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論　文

Estimating the maintenance and repair cost in Life Cycle Cost calculation: A case of automobile ownership in the U.S.

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Abstract

The maintenance and repair cost of durable goods has traditionally been hidden from consumers and yet has been non--negligible part of Life Cycle Cost (LCC) computation. Predicting the maintenance and repair cost is difficult because many of these durable goods do not have constant failure rates. For some durable products such as automobiles, it is often the case that we have at least a rough idea as to their reliability. In this study we propose and illustrate a method to convert automobile reliability data in the U.S. to their monetary maintenance and repair cost. In our method, we first estimate a statistical model from the widely available reliability data. Then we predict the reliability from the model. Finally we convert the predicted reliability to cost figures. The proposed statistical model takes care of the possible bias introduced by partially missing reliability data. Conversion to cost figure is done on the twenty-six 1996-model-year vehicles popular in the U.S. during 1992--1999.

Key Words

Life Cycle Cost; Reliability of Automobile; Nonignorable Nonresponse; Multinomial Logistic Regression Model

ライフサイクルコスト算出における維持および修理費用の推定：アメリカでの自動車所有の例

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＜論文趣旨＞

これまで耐久消費財の維持および修理にかかる費用に関しては，ライフサイクルコスト計算においても無視できない費用であるにもかかわらず消費者はあまり知らされてこなかった．一定の故障頻度を持たない多くの耐久消費財についてその維持および修理費用を推定することは困難である．しかしながら例えば自動車のような財については，少なくともその信頼性に関しては大まかにではあるが情報を得ることができる．そこで本研究ではアメリカ自動車信頼性データから維持・修理費用を算出方法について提案する．この方法ではまず広く利用可能な信頼性データから統計的モデルを推定する．そしてモデルから推定される自動車の信頼性から費用へ変換を行う．ここで用いる統計的モデルでは部分的に欠損している信頼性データから起こりうる偏りの問題に対処することを可能にしている．具体的な費用算出例として1996年モデルイヤーにおいて人気のあった26車種を取り上げた．

＜キーワード＞

ライフサイクルコスト，自動車信頼性，無視できない非応答，多項ロジスティック回帰モデル

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1 Introduction

The "cost" of a product for consumers has traditionally been equated with its price at the time of purchase. For some products, however, this definition of cost can be quite misleading. For example, in the case of many durable goods, significant cost will be incurred in the use and maintenance of the product over a period of years. Life Cycle Cost (LCC), which includes all the costs associated with acquisition, use, maintenance, and disposal, is more reasonable alternative to evaluate such products.

Consumers themselves have become increasingly aware of not only the cost of acquiring but the cost associated with use, maintenance and disposal of the durable products. This awareness has been partially translated into the U.S. regulations. For example, the U.S. government, through the Energy Policy and Conservation Act (EPCA) of 1975, has been asking home appliance manufacturers to disclose energy consumption on their products (McNeill et al. 1979, Hutton et al. 1980).

The EPCA also included a "New Auto Fuel Economy Program," in which Department of Transportation (DOT) was directed to set "corporate average fuel economy" standard for new car starting in model year 1978, and for new light trucks starting in 1979. Each automaker was required to meet the standard, subject to large fines for non-compliance. The program put Environmental Protection Agency (EPA) in charge of measuring fuel economy for each model, of setting up National Vehicle and Fuel Emissions Laboratory to determine car manufacturers' compliance with federal emissions and fuel economy standards. The program asked Department of Energy (DOE) to publish the Fuel Economy Guide as an aid to consumers considering the purchase of a new car. The Guide lists estimates of miles per gallon (mpg) for each vehicle available for the new model year. These estimates have been provided by the EPA.

Of all durable products consumers purchase, automobile is without doubt the most expensive. For example, according to the U.S. Consumer Expenditure Survey in 1998, expenditure on vehicle purchases, gasoline and motor oil and other vehicle expenses amounted to $6,358 or 17.06% of average household expenditure of $37,260.

Consumers tend to have a pretty good idea on acquisition cost of automobile before the time of purchase from the sticker price and price quotation services from such organizations as Consumer Union. By looking at the window-stickers and using the Fuel Economy Guide, consumers can and are expected to roughly estimate the average yearly fuel cost for any vehicle.

It is difficult, however, to predict repair cost for a specific automobile because it varies from one model to another and the average maintenance and repair cost, for example, in the U.S. Consumer Expenditure Survey, does not apply to the particular automobile of consumer's choice. Until now there has been no regulation requiring Federal and State government office to estimate the repair cost of automobile.

There are state government regulations such as the Lemon Laws stipulating the manufacturers to take some responsibility to the defect of the product they manufactured. California Lemon Law – CA Civil Code Section 1793.22 (Tanner Consumer Protection Act) is one such example. Although the Lemon Laws like this one are protecting consumers in their first year of car ownership throughout the country, typical consumers still have at least seven more years to think about the repair cost, because "the median age of cars on the road in 1999 is more than 8 years, compared with $6\frac{1}{2}$ years in 1990" (April 1999 Consumer Reports page 97). Public can consult publications such as Consumer Reports or can access to their website for the frequency of repair of the specific make and model. In this paper we will propose and illustrate a method to convert that knowledge of the frequency of repair to "monetary repair cost."

In current practice, maintenance and repair cost of a general product is estimated through the usage of databases and professional opinions (Taylor 1981). The reason for this is the fact that the repair cost depends on maintainability and reliability parameters. While most electronic components are considered to have constant failure rates (exponential distributions) - which coincidentally simplifies the mathematics for calculating the often used mean time before failure (MTBF) and mean time to repair (MTTR), reliability/maintainability of non-electronic components have non-constant failure rates and can lead to the unwary to intractable mathematics (Fricker 1979, De Neumann 1983). Automobiles, as computerized as they may be, have significant mechanical components. This makes it very difficult to obtain theoretical model of the reliability and maintainability of automobiles, leaving us an only choice of statistical method for tracing them.

Our method is as follows: We first estimate a statistical model regressing the reliability summaries[1] in five point ordinal scale published in the Consumer Reports on several design characteristics of automobile and several attributive dummy variables. We choose these explanatory variables because they are easily available to buyers thinking of purchasing a new car. Then we predict the reliability score from the model. Finally we convert our predicted reliability score to cost figure using the data from several sources.

As an example, we estimate the vehicle-specific maintenance and repair costs in U.S. dollars for twenty-six popular 1996-model-year vehicles in their first eight years of ownership. They are selected from the thirty best-selling passenger cars and the twenty best-selling minivans, SUVs, and pickup trucks in the United States during 1992–1999 and were consistently on the best-selling list throughout the period. Since these popular fifty vehicles and their siblings covered 73.1% of all the vehicles sold in 1996 and covered all market segments—passenger car, minivan, SUV, and pickup truck—important to average consumers, we believe the choice is representative.

This paper is organized as follows. The methods used in estimating the statistical model and converting the model into cost figure are described in section 2. In section 3, the result is presented, and in section 4 we discuss the result. Appendix A explains how we estimated the statistical model. Appendix B describes in detail how we calculated the vehicle-specific ratio for maintenance and repair cost.

2 Methods

Maintenance and repair cost by model and year were in general not available. What we have instead are:

1. Yearly data on average cost for automobile maintenance and repair over *all* consumers from the *Consumer Expenditure Survey*;

2. Estimates of "typical" itemized maintenance and repair cost by model for eight major mechanical

systems for 1996-model-year vehicles compiled from *Mitchell Mechanical Parts & Labor Estimating Guide* 2002 part of which is listed in Table 1;

Table 1: Subsystem and total repair costs for eight major mechanical systems including labor and their reliabilities for 1996-model-year vehicles in 1999.

Major System	Subsystem	Ford Taurus	Honda Accord	Toyota Camry	⋯
A/C	Blower + Heater Core	$461	$973	$551	
	Compressor	$559	$594	$886	
	Total	**$1,020**	**$1,567**	**$1,437**	⋯
	Reliability	4	4	5	
Cooling	Water Pump	$260	$408	$324	
	Radiator + Hose	$671	$383	$558	
	Total	**$931**	**$791**	**$882**	⋯
	Reliability	2	5	5	
Electrical	Window Motor	$150	$182	$316	
	Wiper Motor	$148	$265	$240	
	Total	**$298**	**$447**	**$556**	⋯
	Reliability	2	4	4	
⋮	⋮	⋮	⋮	⋮	

Subsystems corresponding to Augst 2000 issue of *Consumer Reports* were listed.

3. Design characteristics of 1996-model-year vehicles and their sales data from *Ward's Automotive Yearbooks* in 1996 and 1997;

4. The total number of up-to-eight-year-old vehicles of on the road in 1999 from *Ward's Motor Vehicle Facts and Figures* in 2000 in Figure 2;

5. The likelihoods of problems in each of the eight major systems for 1996-model-year vehicle between 1996–2001 from April 1997–2002 *Consumer Reports* part of which is also listed in Table 1;

6. Annual (1996–2001) Classifications of 1996-model-year vehicles into five (three in April 2000 issue and thereafter) reliability categories from April 1997–2002 *Consumer Reports*;

7. Annual (1992–2001) estimates of the number of problems of 1992–2001-model-year vehicles by reliability categories in April 1993–2002 *Consumer Reports*. Table 2 is the estimates for 1996-model-year vehicle.

We will use these data to construct estimates of lifetime maintenance and repair cost. The *Consumer Expenditure Survey* is based on a carefully designed sample, the estimates of "typical" itemized maintenance and repair cost and design characteristics of 1996-model-year vehicles are engineering data, and the total number of up-to-eight-year-old vehicles of on the road is based on sales data. These may be presumed statistically reliable. However the samples on which reliability calculations are based are self-selected: they are solicited by *Consumer Reports*. It seems possible that owners of unreliable automobiles are

Table 2: The annual estimates of the number of problems of 1996-model-year vehicle when its reliability falls into one of the five (three in 1999 and thereafter) categories.

	Reliability Summary				
Year	1 (1)	2 (1)	3 (2)	4 (3)	5 (3)
1996	0.490	0.402	0.283	0.258	0.190
1997	0.775	0.640	0.503	0.382	0.256
1998	0.981	0.859	0.661	0.519	0.297
1999	1.124		0.747	0.450	
2000	1.225		0.889	0.503	
2001	1.352		0.950	0.530	
2002	1.451		1.099	0.679	
2003	1.558		1.223	0.705	

overrepresented in the sample, leading to a sample selection bias. This is aggravated by the fact that if there are too few responses for a given model/model-year in some year, *Consumer Reports* reports a missing value. We next turn to a careful description of the reliability data, and the statistical methodology applied to reduce selection biases.

Predicted Reliability Score vs Reliability Summaries

There have been two automobile reliability scores published in *Consumer Reports*, "predicted reliability score" and "reliability summaries." The reliability summaries are the weighted sum of the problem rates of all problem spots year by year, car by car. *Consumer Reports* described that "the reliability summaries show how each model compares with the overall average for that model year" and "the scores in reliability summaries are on relative scale, compared with the average for all models of the same year, from much worse than average to much better than average" on a five-point scale (April 1998 *Consumer Reports*). The predicted reliability scores, on the other hand, are the judgment based on the three most recent years of reliability summaries. With their auto engineers' knowledge of the current year's models and the reliability data for the past models, *Consumer Reports* claim that they have been able to give reliability prediction for most current models.

Past experiences, however, showed that predicted reliability scores might not be as accurate as the name implied. For example, out of 103, 163 and 150 of 1996-model-year vehicles surveyed in April 1997–1999 issues respectively, 46.6 %, 45.4 %, and 44.0 % of them registered reliability summaries that were different from the reliability scores predicted in April 1996 issue. In this study we chose reliability summaries as the measurement of reliability for two reasons: first it reflected the actual response, not prediction, from the readers in Annual Questionnaire; second the way it was computed—relative to the average for all models of the same year, which can be easily determined—enabled us to calculate vehicle-specific reliability summaries.

Nonignorable Missing Value Problem

There are two potential problems in *Consumer Reports'* reliability summaries: the number of responses from owners of automobiles with few sales might be too limited to reliably evaluate these cars, making "insufficient data" entries to appear in their reliability summaries; comparatively more owners might have responded to their surveys if they had been dissatisfied with the reliability of their own vehicles, either out of obligation to make the information available to public, or simply to convey their frustration.

Especially the"non-ignorable" non-response problem of the latter—in sample survey terminology, a variable **Y** with unit nonresponse is categorized as "non-ignorably missing" if some of the **Y** are missing because of the underlying values it takes—could make the responses from owners of unreliable automobiles overrepresented in the sample and seriously distort the analysis. See appendix A for how these problems were addressed.

Data for Estimating the Statistical Models

Reliability summaries were the response variable for the multinomial cumulative probability logistic regression model in equation (1) in appendix A. We used reliability summaries for 1996 model years published in April 1997–2002 *Consumer Reports.* We assigned scores 5 to 1 to entries of much better than average to much worse than average in 1997 to 1999 issues. In April 2000 issue and thereafter, reliability summaries were recorded on a 3 point-scale—better than average, average, worse than average—and called the "reliability verdict."[2] We assigned scores 3 to 1 to them. There were 84 (47.7%), 35 (19.9%), 47 (26.7%), 48 (27.3%), 53 (30.1%) and 63 (35.8%) missing reliability summaries out of 176 models in 1996, 1997, 1998, 1999, 2000 and 2001 respectively. We coded them as "NA" and included them. The observed data indicator was the response variable for the binomial logistic regression model in equation (3) in appendix A. The models in (1) and (3) were simultaneously estimated.

Due to the quality of the parts, the nature of the design, or the production technique, some models suffer problems at a rate far lower or higher than what one might expect from sheer aging. Explanatory variables for model (1) were: cars' design characteristics—maximum horsepower, displacement in liters, weight in pounds and length in inches; two dummy variables—one indicating manufacturers' country of origin being Japan and the other being Europe[3]—choosing U.S. as baseline; eight "segment" category dummy variables indicating whether a vehicle was small, large, luxury, sport/sporty, coupe, pickup truck, SUV and minivan selecting medium passenger cars as baseline; one dummy variable indicating whether the model was completely redesigned or newly introduced in 1996 by the Big Three (redesigned for short).[4] These data were taken from *Ward's Automotive Yearbook* in 1996. The design characteristics were those of the mid-priced models. We assume sales volume and reliability summary of each model could affect missing entries of its reliability summary, and used the sales figure and reliability score as explanatory variables in model (3).

Converting the Predicted Reliability Summaries into Maintenance and Repair Cost Figure

To estimate the maintenance and repair costs that are in line with those in *Consumer Expenditure Survey,* we proceed as follows. In step 1, we obtain the average maintenance and repair cost *per problem* for all 1996-model-year vehicles. In step 2, we calculate *the expected number of problems* a 1996-model-year vehicle was to encounter each year from 1996 to 2003; In step 3, we calculate a series of ratios of maintenance and repair cost *per problem* for the particular vehicle relative to that for the "average" 1996-model-year vehicle[5] as they—both the particular vehicle and the "average" vehicle—become older from 1996 to 2003; In step 4, we multiply the three numbers in steps 1–3 to obtain the maintenance and repair cost for the vehicle from 1996 to 2003. Steps 2–4 are conducted for each of the thirty passenger cars and the twenty light trucks.

The method depends on availability in step 2 of annual estimates of the number of problems of 1996-model-year vehicles as they age for each of the five (three in 1999 and thereafter) reliability categories. Their 1996–2001 estimates were from *Consumer Reports.* Their 2002 and 2003 estimates were not yet available, but we could substitute those of 1995- and 1994-model-year vehicles in April 2002 *Consumer Reports.* Thus the 1996–2003 estimates were as shown in Table 2. The method also requires in step 3 engineering data on vehicle-specific maintenance and repair costs. They were compiled from *Mitchell Mechanical Parts & Labor Estimating Guide* and were partially listed in Table 1.

If the maintenance and repair cost of a vehicle depended only on how often that vehicle broke down over the eight year period, steps 1 and 2 would suffice. Step 3 is necessary because the itemized maintenance and repair costs vary with vehicles. For instance, we found that in general vehicles made by the Big Three were more problem-prone but less expensive per problem to fix than those made by the Europeans and Japanese because their parts were less expensive. So the maintenance and repair costs for vehicles made by the Big Three would be overestimated without step 3. We describe steps 1 to 3 in detail below.

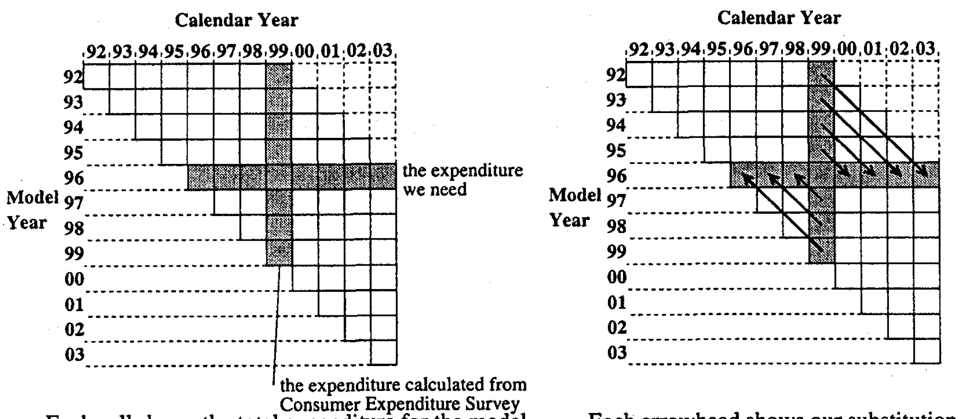
Step 1

What we needed was the *longitudinal* 1996-model-year row sum in Figure 1(a) corresponding to the 1996–2003 total maintenance and repair cost. Dividing this total cost by the total number of problems in 1996–2003 for 1996-model-year vehicles with an average reliability obtains the average maintenance and repair cost *per problem* over the eight years.

However, what we had in the cost for automobile maintenance and repair in *Consumer Expenditure Survey* was *cross-sectional,* that is, it was calculated annually over all households which had varying number of vehicles of diverse models and ages. The column sum corresponding the calendar year 1999 in Figure 1(a) is the total maintenance and repair cost for the vehicles up to eight year old in 1999. Dividing this column sum by the number of up-to-eight-year-old vehicles on the road in 1999 and multiplying the resulting *per vehicle* cost figure by 1.93 vehicles *per consumer unit* in 1999 roughly obtains $664 *per*

Figure 1: Substituting the total maintenance and repair costs for the up-to-eight-year-old vehicles on the road in 1999 to those for 1996-model-year vehicles from 1996 to 2003.

(a) (b)



Each cell shows the total expenditure for the model year vehicles in the calendar year.

Each arrowhead shows our substitution on the expenditure.

consumer unit for automobile maintenance and repair in 1999 *Consumer Expenditure Survey.* Here we assume that the cost for vehicles more-than-eight-year-old resembles that for vehicles up-to-eight-year-old.[6]

However, note first that the total number of problems 1996-model-year vehicles estimated to have encountered during 1996–1999 were close to those of 1999–1996-model-year vehicles in 1999 as shown in Table 3.[7]

Table 3: The total numbers of problems of 1996-model-year vehicles in 1996–1999 were close to those of 1–4 year old vehicles in 1999.

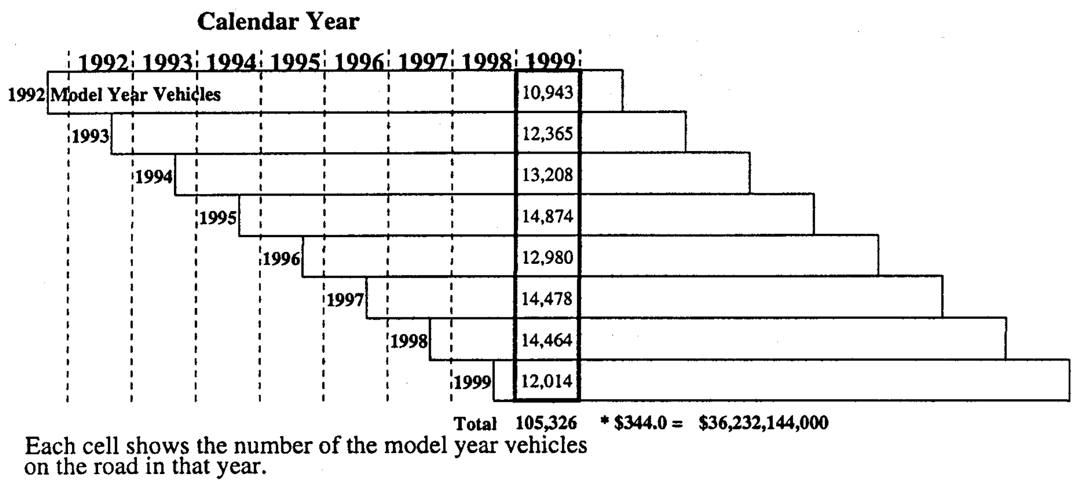
	Calendar Year			
Model Year	1996	1997	1998	1999
1989	20,623,884			
1990	17,349,773	18,173,723		
1991	14,087,572	16,408,082	16,480,277	
1992	10,882,526	12,999,231	14,214,657	15,451,516
1993	10,015,812	11,148,243	13,151,564	15,171,855
1994	8,761,880	9,350,964	11,194,401	13,577,824
1995	7,024,337	10,102,470	11,061,703	12,955,254
1996	**2,907,825**	**6,802,572**	**8,665,049**	**9,696,060**
1997		2,166,770	6,927,226	**8,846,058**
1998			2,231,270	**6,176,128**
1999				**3,207,738**

Note also that the costs for automobile maintenance and repair in *Consumer Expenditure Survey* were stable at $651 per consumer unit with average number of 1.9 vehicles in 1992–1999. These two facts allowed us to substitute, for instance, the total maintenance and repair cost for one-year-old vehicles in

1999—cell in 1999 model year row and 1999 calendar year column—for the total maintenance and repair cost for 1996-model-year vehicles in their first year—cell in 1996 model year row and 1996 calendar year column—as indicated in Figure 1(b).

To turn the total cost figure into a *per problem* one, we used two numbers other than the $344 per vehicle (that is, $664 per consumer unit with 1.93 vehicles in 1999 *Consumer Expenditure Survey*) for automobile maintenance and repair: the total number—105,326,000—of up-to-eight-year-old vehicles on the road in 1999 in Figure 2 from *Ward's Motor Vehicle Facts and Figures* in 2000 to obtain the total maintenance and repair cost of $36,232,144,000≈$344×105,326,000; the numbers of problems—0.27 to 1.41—for 1992–1999 model year vehicles with average reliability in Figure 3 to obtain the total number—85,214,000—of problems for up-to-eight-year-old vehicles on the road in 1999. The average maintenance

Figure 2:
The total number of up-to-eight-year-old vehicles on the road in 1999 (in thousands) and their total maintenance and repair cost.



and repair cost per problem for up-to-eight-year-old vehicles was thus $425≈$36,232,144,000/85,214,000. This will be used in step 4. Notice that a mechanism was embedded in step 1 to guarantee that our estimated maintenance and repair cost match the cost for automobile maintenance and repair in *Consumer Expenditure Survey.*

Step 2

In step 2, we first used model (1) in appendix A to predict five-category—much better than average to much worse than average—reliability distributions (three categories in 1999 and thereafter) of the thirty best-selling passenger cars and the twenty best-selling light trucks each year from 1996 to 2003. Since we could not estimate these probabilities for 2002 and 2003,[8] we used the average of 1996 to 2001 as a proxy for these two years. For instance, 1996 Ford Taurus—the most popular passenger car in 1996—was estimated to have the reliability distribution in Table 4.

Figure 3: The total number of problems for up-to-eight-year-old vehicles on the road in 1999.

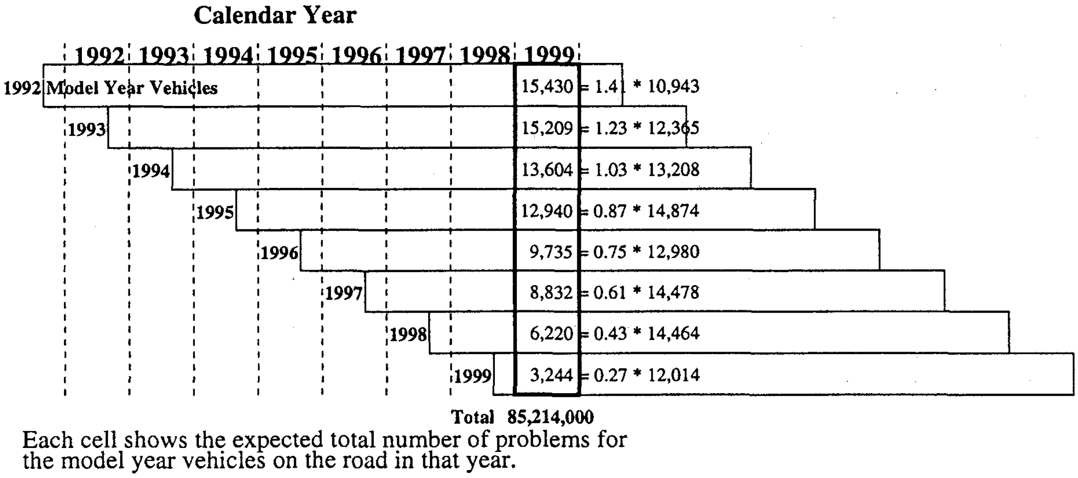


Table 4: Estimated reliability distribution for 1996 Ford Taurus.

Year	Reliability Summaries					Average	*Consumer Reports*
	1 (1)	2 (1)	3 (2)	4 (3)	5 (3)		
1996	0.113	0.281	0.421	0.140	0.045	2.72	1
1997	0.121	0.297	0.421	0.117	0.043	2.66	1
1998	0.638	0.230	0.115	0.012	0.005	1.52	2
1999	0.617		0.329	0.054		1.44	1
2000	0.528		0.389	0.083		1.55	2
2001	0.763		0.201	0.036		1.27	2
2002–03	0.598		0.313	0.089		1.49	NA

From Tables 2[9] and 4, 1996 Ford Taurus' expected numbers of problems in 1996–2003 was obtained as in Table 5.[10]

Table 5: 1996 Ford Taurus' expected number of troubles.

Calendar Year							
1996	1997	1998	1999	2000	2001	2002	2003
0.33	0.55	0.91	0.96	1.03	1.24	1.27	1.38

Step 3

In step 3, we calculated yearly ratio of maintenance and repair cost *per problem* for each vehicle relative to that for the 1996-model-year vehicle whose maintenance and repair cost *per problem* was average from 1996 to 2003. Taking the best selling 1996 Ford Taurus as an example, we explain how we proceeded.

Table 1 in an unabridged form gives how likely one is to face problems in eight major mechanical systems—air conditioner, cooling system, electrical system, engine, fuel system, ignition system, suspension, and transmission—and their itemized approximate repair costs for the fifty most popular

1996-model-year vehicles. If we multiply the likelihoods and their associated costs and add them up over the eight major mechanical systems to obtain yearly maintenance and repair cost of a 1996-model-year Ford Taurus in 1999, the resulting figure of $1,034 overshoot by far the actual maintenance and repair cost because this calculation implies that this Ford Taurus requires complete repair or replacement with new parts of the eight systems every time one of those systems breaks down. If we conduct the same calculations for the fifty vehicles,[11] the resulting estimated average figure of $1,216 far exceeds the actual maintenance and repair cost as reported in *Consumer Expenditure Survey.* However we assume that the ratio of the maintenance and repair cost per problem for the 1996 Ford Taurus relative to the 1996-model-year vehicle with average cost per problem approximates the same ratio based on the actual payment or expenditure. The assumption implies that a vehicle whose maintenance and repair cost would be high if it was repaired completely or its parts was replaced by the new ones should cost owners proportionally higher when it was repaired partially or its parts were replaced with used or rebuilt ones. The assumption was needed because *Consumer Reports* were asking for reliabilities on the major systems, but not on their subsystems. Thus we could not estimate the average cost of breakdowns, some of which require replacement of the whole major system, others which require partial replacement and still others might require only minor adjustments. For instance, the maintenance and repair cost ratios of 1996 Ford Taurus were shown in Table 6. Details of these calculations are in appendix B.

Table 6: The maintenance and repair expenditure ratios of 1996 Ford Taurus relative to the average of the fifty popular vehicles.

	Calendar Year							
	1996	1997	1998	1999	2000	2001	2002	2003
Ratio	0.93	0.79	0.79	0.85	0.88	0.88	1.10	1.25

3 Results

Reliability Model Estimation

Estimated parameters of the final models are listed in Table 7. Confirming conventional wisdom, 1996-model-year vehicles made by Japanese manufacturers had consistently higher reliability summaries than those made by the U.S. or European manufacturers in 1996–2001 at 99% level of significance.

Other covariates were significant in some years. The 1996-model-year European (German and Swedish) vehicles were more reliable than U.S. vehicles in 1997 and 2001. Coupes, minivans, and pickup trucks were significantly less reliable than medium cars in three years following their purchases, but their reliabilities held up well afterwards. On the other hand, there were persistent reliability problems for SUVs relative to medium cars. The automobiles completely redesigned or newly introduced in 1996 by the Big Three were possibly unreliable in 1996 and they were significantly unreliable at 99% level of significance in 1998.

Table 7: Estimated parameters of the multinomial logistic regression models.

Model (1) for reliability summaries						
Variable	1996	1997	1998	1999	2000	2001
θ_1	−4.88***	−3.59***	−3.86***	−3.06***	−2.87***	−1.92*
	(-4.46)	(-4.45)	(-3.66)	(-3.34)	(-2.98)	(-1.89)
θ_2	−3.25***	−1.94**	−2.55**	-0.672	-0.581	0.194
	(-3.19)	(-2.57)	(-2.50)	(-0.77)	(-0.63)	(0.19)
θ_3	-1.34	0.0464	-0.415			
	(-1.37)	(0.06)	(-0.42)			
θ_4	0.240	1.48*	0.816			
	(0.24)	(1.93)	(0.80)			
Displacement	0.608**					
	(2.33)					
Max. horsepower		0.00805*	0.00849*	0.0177***	0.0149***	0.0155**
		(1.81)	(1.75)	(3.22)	(2.58)	(2.45)
Japan	−3.36***	−3.27***	−2.94***	−2.80***	−3.74***	−4.48***
	(-5.25)	(-7.00)	(-6.22)	(-5.57)	(-6.15)	(-6.34)
Europe		−1.30**	-0.76	-0.99	-1.07	−2.14***
		(-2.01)	(-1.11)	(-1.45)	(-1.56)	(-2.97)
Small	2.13***		0.87			
	(3.06)		(1.35)			
Large		-0.94		−1.33**	−1.54**	−2.00***
		(-1.47)		(-1.98)	(-2.20)	(-2.68)
Luxury		-1.40		−2.09**	-1.88	−2.59*
		(-1.25)		(-2.54)	(-1.50)	(-1.89)
Coupe	4.27***	2.57***	2.59***	0.98	1.20	
	(3.45)	(3.22)	(3.01)	(1.06)	(1.28)	
Sporty		1.89***	1.98**			2.15
		(2.70)	(2.42)			(1.27)
Minivan	2.67***	1.91***	1.54**	0.79	0.83	1.48*
	(3.15)	(3.32)	(2.53)	(1.34)	(1.36)	(1.74)
SUV	1.34**	1.47***	2.02***	2.05***	1.47**	
	(1.96)	(2.75)	(3.58)	(2.97)	(2.19)	
Pickup truck	1.80***	1.62***	1.26**			-0.83
	(2.70)	(2.64)	(2.05)			(-1.16)
Redesigned	1.00		2.73***			
	(1.03)		(2.82)			
Model (3) for observed indicator						
Variable	1996	1997	1998	1999	2000	2001
Intercept	−1.46*	−2.82**	−1.44*	−2.80***	−1.68**	−2.48***
	(-1.87)	(-2.45)	(-1.83)	(-2.75)	(-1.96)	(-3.30)
Sales Volume	$3.70 * 10^{-5}$***	$15.8 * 10^{-5}$***	$7.01 * 10^{-5}$***	$10.9 * 10^{-5}$***	$7.31 * 10^{-5}$***	$6.12 * 10^{-5}$***
	(5.70)	(4.76)	(5.06)	(5.28)	(5.32)	(5.70)
Reliability summary	-0.234	0.203	0.0294	0.294	-0.0112	0.293
	(-1.53)	(0.79)	(0.15)	(0.75)	(-0.04)	(1.05)
AIC	320.34	411.16	399.77	281.5	273.69	248.07

*,**, and *** represent significance at the ten, five, and one percent level respectively.
Asymptotic t−values of the coefficients appear in parentheses.

Missing entries in reliability summaries consistently showed that it was highly correlated with the sales volume. A vehicle with higher sales volume was less likely to have its reliability summary missing. We could not totally exclude the possibility that owners of a relatively new automobile whose reliability was worse than average responded to *Consumer Reports'* Annual Questionnaire more frequently than those whose automobile showed better than average reliability. For example, in 1996 automobiles with higher reliabilities were more likely to have their reliability summaries missing, implying that the overall reliability average for 1996-mode-year vehicles could have been deflated by this self-selection bias. Because *Consumer Reports* evaluates the reliability of automobiles on a relative scale within a model year, this meant that the reliability summaries of 1996-model-year vehicles in 1996 could have been inflated.

Maintenance and Repair Costs

We listed the estimated maintenance and repair expenditures for the twenty-six consistently popular passenger cars and light trucks mentioned on page 3. In decreasing order of sales in 1996 within their categories, they were: Ford Escorts, Saturn SLs, Honda Civics, Chevrolet Cavaliers, and Toyota Corollas as small cars; Ford Tauruses, Honda Accords, Toyota Camries, Chevrolet Luminas, Nissan Maximas, and Pontiac Grand Prixes as medium cars; Buick LeSabres, Ford Crown Victorias, Cadillac DeVilles, and Lincoln Town Cars as large cars;[12] Ford Explorers, Chevrolet Blazers, Jeep Grand Cherokees as SUVs; Dodge Grand Caravans and Ford Windstars as minivans; Ford Rangers, Chevrolet S-10 pickup trucks, and Dodge Dakotas as compact pickup trucks; Ford F-150s, Chevrolet C1500s, Dodge Ram pickup trucks as fullsize pickup trucks. Their estimated maintenance and repair expenditures adjusted for the rate of inflation in the CPI[13] are listed in Table 8.

4 Discussion

The result in section 3 tells us how much one should realistically expect to pay to maintain and repair the popular twenty-six vehicles purchased in 1996 in their median life time of eight years. We found that on average owners would pay \$2,434, \$2,833, \$2,991, \$3,307, \$3,096, or \$3,008 in 1996 U.S. dollars during 1996–2003 respectively if they operated one of the listed small cars, medium cars, large cars, SUVs, minivans, or pickup trucks purchased in 1996. As expected the small cars were least expensive to maintain and repair and the medium cars follow.

The small and medium passenger cars produced by Japanese manufacturers were inexpensive to maintain and repair relative to the comparable models from the Big Three because they were more reliable, although their higher parts costs partially offset their reliability advantage. For instance, Ford Escorts would encounter 1.6 times more problems than Honda Civics in their lifetime, but their maintenance and repair expenditures differed by only \$290 for the first eight years. Similarly Ford Tauruses was nowhere near as expensive as their problem rates indicated because their cost of repair was lower than that of Honda Accords, Toyota Camries, or Nissan Maximas.

Table 8: Vehicle-specific expected maintenance and repair expenditures for the twenty-six 1996-model-year vehicles (in 1996 U.S dollars).

		Estimated Maintenance and Repair Expenditure(U.S.$)								
	Model	1996	1997	1998	1999	2000	2001	2002	2003	Total
Small Car	Ford Escort	127	152	222	229	247	339	396	388	2,100
	Saturn S	153	191	340	353	509	717	676	703	3,641
	Honda Civic	95	129	178	200	206	232	399	372	1,810
	Chev. Cavalier	109	185	258	323	350	510	580	543	2,858
	Toyota Corolla	111	144	197	239	223	227	298	320	1,758
Medium Car	Ford Taurus	132	185	306	349	386	463	598	734	3,153
	Honda Accord	127	164	197	288	410	416	414	558	2,574
	Toyota Camry	106	163	180	297	368	411	446	545	2,516
	Chev. Lumina	116	219	308	390	408	603	650	458	3,151
	Nissan Maxima	110	186	225	331	282	274	346	463	2,218
	Pontiac Grand Prix	116	235	367	456	465	530	569	647	3,386
Large Car	Buick LeSabre	116	174	308	353	387	557	490	464	2,849
	Ford Crown Victoria	128	168	245	303	278	360	378	500	2,360
	Cadillac DeVille	248	329	440	516	609	738	779	938	4,596
	Lincoln Town Car	106	145	239	286	310	313	408	349	2,157
SUV	Ford Explorer	116	199	262	302	337	423	370	540	2,549
	Chev. Blazer	364	355	432	446	484	506	580	612	3,779
	Jeep Grand Cherokee	121	241	349	422	504	610	626	719	3,592
Minivan	Dodge Grand Caravan	155	203	298	341	377	528	510	551	2,963
	Ford Windstar	136	184	231	346	419	500	679	734	3,229
Compact Pickup Truck	Ford Ranger	138	172	232	257	242	331	302	484	2,160
	Chev. S-10 Pickup	313	367	292	369	442	467	588	512	3,350
	Dodge Dakota	155	311	333	433	423	570	627	607	3,457
Fullsize Pickup Truck	Ford F-150	137	195	276	288	352	351	459	542	2,600
	Chev. C1500 Pickup	132	259	301	359	378	478	446	499	2,852
	Dodge Ram Pickup	172	308	392	476	483	549	648	603	3,630

In this paper we proposed a new method to estimate lifetime maintenance and repair cost of durable goods whose component-wise reliability and parts and labor costs are either well documented or widely available. First we profiled their reliability characteristics using sophisticated statistical techniques. Second we proposed a method to convert cross-sectional macro data on maintenance and repair expenditure per average household in national economic statistics into longitudinal maintenance and repair cost per average good. Finally discrepancies from the average were dealt in the form of ratio to the average incorporating both frequencies and costs of maintenance and repair. The method in principle can be applied to any consumer oriented durable goods with significant mechanical components when their reliability and parts and labor costs are documented. In this sense this paper makes a new contribution to management accounting literature.

Appendix A　Multinomial Regression Model for Potentially Non-ignorably Missing Survey Responses

In appendix A, we summarize the method for estimating parameters in multinomial logistic regression models when the response variable **Y** was partially missing and the missing data mechanism was potentially nonignorable, and the explanatory variables were fully observed. This framework was presented by Ibrahim and Lipsitz (1996) for binomial logistic regression model. We extended the model to multinomial logistic regression.

The model consists of the joint distribution of the multinomial ordinal response variable $\mathbf{Y}$ and the binomial observed data indicator $\mathbf{R}$, ith of which takes 0 when the ith of the $\mathbf{Y}$ is not oberved. Since the explanatory variables $\mathbf{X}$ are fully observed, they are treated as fixed throughout. In this paper $\mathbf{Y}$ represents reliability scores and takes integral value from 1 (much worse than average) to 5 (much better than average) and $\mathbf{X}$ includes several design characteristics, car types, and the country origins of car manufacturers. We express the joint distribution $\mathbf{R}$ and $\mathbf{Y}$ by specifying the conditional distributions $\mathbf{Y}|(\boldsymbol{\theta},\boldsymbol{\beta})$ and $\mathbf{R}|\mathbf{Y},\boldsymbol{\alpha}$, where $(\boldsymbol{\theta},\boldsymbol{\beta})$ and $\boldsymbol{\alpha}$ are assumed to be distinct sets of indexing parameters for their respective distributions.

Suppose y_i, $i=1,\ldots,n$, are independent multinomial observations with the cumulative probability ψ_{ij} up to and including jth category. Further, let $\boldsymbol{x}_i=(x_{i1},\cdots,x_{ip})$ denote the $1\times p$ observed vector of explanatory variables for the ith observation, $\mathbf{X}$ is an $n\times p$ matrix of explanatory variables, and let $\boldsymbol{\beta}=(\beta_1,\cdots,\beta_p)^T$ denote the corresponding $p\times 1$ column vector of regression coefficients. We use a parallel logistic regression model for the ψ_i's

$$\log\{\psi_{ij}/(1-\psi_{ij})\}=\theta_j-\boldsymbol{\beta}^T\boldsymbol{x}_i,\qquad j=1,\ldots,k-1 \tag{1}$$

with the likelihood for $y_i|\boldsymbol{x}_i$ is given by

$$\begin{aligned} &L_{y_i}(\boldsymbol{\theta},\boldsymbol{\beta}) && (2)\\ &= \Pi_{j=1}^{k}(\psi_{ij}-\psi_{ij-1})^{y_{ij}}\\ &= \Pi_{j=1}^{k}\left\{\frac{\exp(\theta_j-\boldsymbol{\beta}^T\boldsymbol{x}_i)}{1+\exp(\theta_j-\boldsymbol{\beta}^T\boldsymbol{x}_i)}-\frac{\exp(\theta_{j-1}-\boldsymbol{\beta}^T\boldsymbol{x}_i)}{1+\exp(\theta_{j-1}-\boldsymbol{\beta}^T\boldsymbol{x}_i)}\right\}^{y_{ij}}, \end{aligned}$$

where $y_{ij}=1$ if $y_i=j$, $y_{ij}=0$ otherwise.

The negative sign in (1) is a convention ensuring that large values of $\boldsymbol{\beta}^T\boldsymbol{x}$ lead to an increase of probability in the higher-numbered categories. Since θ_j estimates logistic transformation of the cumulative probability up to and including category j, $\theta_1\le\theta_2\le\cdots\le\theta_{k-1}$ must be satisfied.

The observed data indicator for the ith response y_i can be written as

$$r_i=\begin{cases}1 & \text{if } y_i \text{ is observed,}\\ 0 & \text{if } y_i \text{ is missing,}\end{cases}$$

for $i=1,\ldots,n$. The vector $\boldsymbol{r}=(r_1,\ldots,r_n)^T$ is $n\times 1$ column vector of observed data indicators. We specify a logistic regression model for the r_i's. Let $\boldsymbol{z}_i=(\boldsymbol{x}_i,y_i)$ and let $\boldsymbol{\alpha}=(\alpha_1,\ldots,\alpha_{p+1})^T$ be a $(p+1)\times 1$ column vector of indexing parameters for r_i. We define $p_i=\Pr\{r_i=1|\boldsymbol{z}_i,\boldsymbol{\alpha}\}$ and the logisitic regression model for the p_i's is

$$\log\{p_i/(1-p_i)\}=\boldsymbol{z}_i\boldsymbol{\alpha}, \tag{3}$$

where the likelihood for r_i is

$$\begin{aligned} L_{r_i|y_i}(\boldsymbol{\alpha}) &= \left(\frac{p_i}{1-p_i}\right)^{r_i}(1-p_i) && (4)\\ &= \exp\left[r_i\boldsymbol{z}_i\boldsymbol{\alpha}-\log\{1+\exp(\boldsymbol{z}_i\boldsymbol{\alpha})\}\right]. \end{aligned}$$

If $\alpha_{p+1} \neq 0$ or α_{p+1} is significantly different from zero, then the missing data mechanism depends on y_i and thus nonignorable. If $\alpha_{p+1} = 0$, then $f(r_i|\boldsymbol{z}_i, \boldsymbol{\alpha})$ does not depend on y_i, but may depend on $\boldsymbol{x}_i$. When this happens the missing data mechanism is referred as ignorable. If $\alpha_2 = \cdots = \alpha_{p+1} = 0$, then the observed sample is effectively random subsample of the sample.

Under the assumption that $\boldsymbol{\alpha}$ and $(\boldsymbol{\theta}, \boldsymbol{\beta})$ are distinct sets of indexing parameters, the log-likelihood for all of the observations can be decomposed from (2) and (4) as

$$\begin{aligned} l(\boldsymbol{\tau}) &= \sum_{i=1}^{n} l(\boldsymbol{\tau}; \boldsymbol{x}_i, y_i, r_i) = \sum_{i=1}^{n} \{l_{y_i}(\boldsymbol{\theta}, \boldsymbol{\beta}) + l_{r_i|y_i}(\boldsymbol{\alpha})\} \qquad (5) \\ &= \sum_{i=1}^{n} \Bigg[y_{ij} \log \left\{ \frac{\exp(\theta_j - \boldsymbol{\beta}^T \boldsymbol{x}_i)}{1 + \exp(\theta_j - \boldsymbol{\beta}^T \boldsymbol{x}_i)} - \frac{\exp(\theta_{j-1} - \boldsymbol{\beta}^T \boldsymbol{x}_i)}{1 + \exp(\theta_{j-1} - \boldsymbol{\beta}^T \boldsymbol{x}_i)} \right\} \\ &\qquad + r_i \boldsymbol{z}_i \boldsymbol{\alpha} - \log\{1 + \exp(\boldsymbol{z}_i \boldsymbol{\alpha})\} \Bigg], \end{aligned}$$

where $\boldsymbol{\tau} = (\theta_1, \ldots, \theta_{k-1}, \beta_1, \ldots, \beta_p, \alpha_1, \ldots, \alpha_{p+1})^T$ is a $(k + 2p) \times 1$ column vector of logistic regression parameters and $l(\boldsymbol{\tau}; \boldsymbol{x}_i, y_i, r_i)$ is the contribution to the log-likelihood from the ith observation. The log-likelihood in (5) essentially treats the y_i's as missing covariates in the model for $(r_i|\boldsymbol{z}_i, \boldsymbol{\alpha})$. Thus following Ibrahim and Lipsitz (1996), the maximum likelihood estimates of $\boldsymbol{\tau}$ can be obtained via the EM algorithm by maximizing the expected log-likelihood whose ith individual contribution is

$$\begin{aligned} & E[l(\boldsymbol{\tau}; \boldsymbol{x}_i, y_i, r_i)] \qquad (6) \\ &= \begin{cases} \sum_{y_i=1}^{k} l(\boldsymbol{\tau}, \boldsymbol{x}_i, y_i, r_i) f(y_i|r_i, \boldsymbol{x}_i, \boldsymbol{\tau}) & \text{if } y_i \text{ is missing,} \\ l(\boldsymbol{\tau}; \boldsymbol{x}_i, y_i, r_i) & \text{if } y_i \text{ is observed.} \end{cases} \end{aligned}$$

The E-step in (6) takes the form of a weighted log-likelihood with the conditional probabilities $f(y_i|r_i, \boldsymbol{x}_i, \boldsymbol{\tau})$ of the missing data given the observed data playing the role of ratios. The M-step maximizing the function in (5), which is equivalent to completing data maximum likelihood with each incomplete observation replaced by a set of weighted "filled-in" observations with weight $f(y_i|r_i, \boldsymbol{x}_i, \boldsymbol{\tau})$.

To obtain the asymptotic covariance matrix of $\hat{\boldsymbol{\tau}}$, we need the observed information matrix $\boldsymbol{I}(\boldsymbol{\tau})$. We use the formula in Louis (1982) to compute the observed information in terms of complete-data quantities.

Appendix B　Calculating Vehicle-specific Ratios of Maintenance and Repair Cost

We obtained the yearly ratio of maintenance and repair cost in six stages. First, we calculated *pseudo* vehicle-specific expected repair cost using the frequency-of-repair charts in April 1997–2002 *Consumer Reports*[14] and the cost figures of the eight major mechanical systems for the fifty models from the *Mitchell Mechanical Parts & Labor Estimating Guide* in 2002. For instance, with the frequency-of-repair charts and the cost figures of 1996-model-year Ford Tauruses in Table 9, we calculated in Table 10 expected repair costs of 1996-model-year Ford Tauruses in 1996–2003 if complete repair or replacement with new parts were required for the eight major mechanical systems every time at least one of their subsystems broke down.[15]

Table 9: Frequency of repair charts of 1996-model-year Ford Taurus in 1996–2003 and the cost figures (in U.S. dollar).

	Calendar Year								
Major System	1996	1997	1998	1999	2000	2001	2002	2003	Repair Cost
A/C	0.010	0.010	0.035	0.035	0.035	0.035	0.121	0.121	1,019
Cooling	0.010	0.035	0.035	0.121	0.072	0.072	0.181	0.181	931
Electrical	0.035	0.072	0.072	0.121	0.121	0.121	0.121	0.121	298
Engine	0.010	0.010	0.010	0.035	0.035	0.035	0.121	0.181	4,001
Fuel	0.035	0.035	0.035	0.035	0.072	0.072	0.072	0.072	1,378
Ignition	0.010	0.035	0.035	0.035	0.035	0.035	0.035	0.035	587
Suspension	0.035	0.121	0.121	0.121	0.121	0.121	0.121	0.121	748
Transmission	0.035	0.072	0.072	0.072	0.072	0.072	0.072	0.181	1,535
Total Frequency of Repair	0.180	0.389	0.414	0.573	0.561	0.561	0.841	1.012	

Table 10: 1996-model-year Ford Taurus' expected repair costs for the eight major mechanical systems in 1996–2003 if complete repair or replacement with new parts were required everytime one of their subsystems broke down.

	Calendar Year							
Major System	1996	1997	1998	1999	2000	2001	2002	2003
A/C	10	10	36	36	36	36	123	123
Cooling	9	33	33	112	67	67	169	169
Electrical	10	21	21	36	36	36	36	36
Engine	40	40	40	140	140	140	482	725
Fuel	48	48	48	48	98	98	98	98
Ignition	6	21	21	21	21	21	21	21
Suspension	26	90	90	90	90	90	90	90
Transmission	54	110	110	110	110	110	110	278
Expected Repair Cost (U.S.$)	204	373	398	592	597	597	1,129	1,540

Second, we obtained the expected repair cost *per problem* for each of the fifty vehicles. For 1996-model-year Ford Tauruses, for instance, this meant that dividing the expected repair cost at the bottom of Table 10 by the total frequency of repairs at the bottom of Table 9. The result was shown in Table 11.

Third, we obtained the expected total repair cost for each of the fifty vehicles first by multiplying the expected repair cost in 1996–2003 for the 1996-model-year vehicle with the numbers of 1996-model-year vehicles on the road in 1996–2003 respectively and then by aggregating the resulting numbers. We assumed all the vehicles purchased in 1996 remained on the road during the period. The sales volume information was taken from *Ward's Automotive Yearbook* in 1997. For instance, Ford Taurus' expected total repair cost was $2,177,736,000 in Table 12. We repeated this process for the fifty vehicles and added

Table 11: The expected repair cost per problem for 1996-model-year Ford Taurus if complete repair or replacement with new parts were required everytime one of their subsystems broke down.

Calendar Year							
1996	1997	1998	1999	2000	2001	2002	2003
204/0.180 =1,133	373/0.389 =959	398/0.414 =963	592/0.573 =1,034	597/0.561 =1,065	597/0.561 =1,065	1,129/0.841 =1,341	1,540/1.012 =1,522

Table 12: 1996 Ford Taurus' 1996–2003 expected total repair cost if complete repair or replacement with new parts were required everytime one of their subsystems broke down (in thousand dollars).

	Calendar Year								Expected Total
	1996	1997	1998	1999	2000	2001	2002	2003	Repair Cost
Repair Cost per Vehicle	204	373	398	592	597	597	1,129	1,540	
# of the Vehicle	401,049	401,049	401,049	401,049	401,049	401,049	401,049	401,049	
Total (In Thousands)	81,779	149,465	159,684	237,583	239,451	239,451	452,593	617,731	2,177,736

them to obtain the expected total repair cost for the fifty vehicles of up to eight year old combined—$42,051,478,000.

Fourth, we computed the total number of problems each of the fifty 1996-model-year vehicles was expected to have encountered. For example, the expected total number of problems 1996-model-year Ford Tauruses had/will have in 1996–2003 was 1,816,000 as in Table 13. We aggregated them to obtain

Table 13: The expected total number of problems for 1996-model-year Ford Taurus during 1996–2003 period

	Calendar Year								Total Number
	1996	1997	1998	1999	2000	2001	2002	2003	of Problems
# of Problems per Vehicle	0.180	0.389	0.414	0.573	0.561	0.561	0.841	1.012	
# of the Vehicle	401,049	401,049	401,049	401,049	401,049	401,049	401,049	401,049	
Total (In Thousands)	72	156	166	230	225	225	337	406	1,816

the expected total number of problems in 1996–2003 for the fifty vehicles combined—34,594,000.

Fifth, we obtained the average repair cost per problem—$1,216—by dividing their expected total repair cost—$42,051,478,000—for the fifty models combined by their expected total number—34,594,000—of problems.

Sixth, we divided the expected repair costs per problem in 1996–2003 for a 1996-model-year vehicle by the average repair cost per problem—$1,216—for the fifty models combined to obtain the yearly ratio for the particular vehicle in 1996–2003. The 1996–2003 ratios of 1996-model-year Ford Tauruses were calculated in Table 14.

We think these calculations were warranted because there were significant differences in repair costs among the eight major mechanical systems and because there were significant vehicle-to-vehicle differences in likelihoods of breakdown in the eight major mechanical systems. For example, engine is in general

Table 14: The maintenance and repair expenditure ratios for 1996 Ford Taurus.

	Calendar Year							
	1996	1997	1998	1999	2000	2001	2002	2003
Ratio	1,133 /1,216 =0.93	959 /1,216 =0.79	963 /1,216 =0.79	1,034 /1,216 =0.85	1,065 /1,216 =0.88	1,065 /1,216 =0.88	1,341 /1,216 =1.10	1,522 /1,216 =1.25

much more costly to repair than electrical system, but much less likely to break down. Thus vehicles with many electrical system breakdowns may end up having smaller ratio than vehicles with a single engine trouble.

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Notes

[1]In April 2000 issue and thereafter, reliability summaries were recorded on a 3 point-scale.

[2]We have strong reason to believe the five-point scale in 1997 to 1999 issues can be converted to the three-point scale in 2000–2002 issues by merging two extreme categories into one category. Thus the "much better than average" and "better than average" reliability summaries in 1997–1999 *Consumer Reports* jointly corresponded to the "better than average" reliability verdict in 2000–2002 issues. So did the "much worse than average" and "worse than average" reliability summaries in 1997–1999 issues to the "worse than average" reliability verdict in 2000–2002 issues. See Table 4.

[3]In the 1996 model year, they were German and Swedish automobiles.

[4]This variable was introduced to capture the relatively large decline in reliability reported by *Consumer Reports* of the automobiles made by the Big Three in the first year of introduction or of complete redesign. We tried similar variables for automobiles made by European and Japanese manufacturers, but they were insignificant.

[5]The "average" 1996-model-year vehicle is defined as the one whose maintenance and repair cost *per problem* was average.

[6]Although older vehicles tend to break down more often, this does not necessarily translate into their higher maintenance and repair costs: owners of those vehicles are more likely to postpone some repairs or defer some maintenance work, and if they choose to have their vehicles repaired, they are more likely to opt for used or rebuilt parts.

[7]To obtain the total number—2,907,825—of problems 1996-model-year vehicles were expected to have had in 1996, we multiplied the estimated number of problems—0.283 in Table 2—of 1996-model-year vehicle with average reliability in 1996 by the number—10,275,000 in *Ward's Motor Vehicle Facts and Figures* in 2000—of 1996-model-year vehicles on the road in 1996.

[8]Reliability verdicts were not yet available and so statistical models could not be estimated for these two years.

[9]In order to derive the total number of problems in 1999 in Figure 3, we used the estimates of the number of problems—0.27 to 1.41—for one-to-eight-year-old vehicles in 1999 with average reliability. In Table 2, on the other hand, we listed the estimates of the number of problems as 1996-model-year vehicles aged. Therefore the estimate of the number of problems in average reliability entry in Table 2 did not have to coincide with those in figure 3 except that of 0.747 (rounded to 0.75 in the figure) for 1996-model-year vehicle in 1999.

[10]For instance, 1996 Taurus' expected number of problems was calculated in the year 1996 to be $0.113 \times 0.490 + \cdots + 0.045 \times 0.190 = 0.33$.

[11]Essentially we assume here that the joint distribution of the overall repair costs and of the annual expected number of problems for the excluded vehicles is similar to that of the included vehicles. As mentioned, these popular fifty vehicles and their siblings covered 73.1% of all the vehicles sold in 1996, and we believe the choice is representative.

[12]Cadillac DeVilles, and Lincoln Town Cars were categorized as luxury cars in April 2000 *Consumer Reports*, but they were classified as large cars in April 1996.

[13]Average rate of inflation in CPI during 1996–2001 was 2.45% a year.

[14]The frequency-of-repair charts show the proportion of owners who have reported serious problems for each trouble spot of each model on a five-point scale. The best score 5 indicates that 2.0% or fewer vehicles suffered a serious problem, score 4—2.0% to 5.0%, score 3—5.0% to 9.3%, score 2—9.3% to 14.8% and score 1—more than 14.8% were afflicted with the problem. We assigned the midrange problem rates respectively for the first four of the five categories. We assigned 18.1% for the score 1 category. To do so, we first estimated a simple regression model of how the percentage increment between the neighboring categories were correlated with the category increment using the first four categories and then extrapolating the result to the score 1 category.

[15]The eight major mechanical systems and the subsystems we picked up are those in August 2000 issue of Consumer Reports.

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